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FREE (FIELD REMOTE ENVIRONMENT EVALUATION) SENSOR CONCEPT DEVEL--ETC(U)  
JUL 80 J HARPER, J LEWIS, T LONG DNAU001-79-C-0213

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**FREE (FIELD REMOTE ENVIRONMENT  
3 EVALUATION) SENSOR CONCEPT  
3 DEVELOPMENT**

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1 July 1980

Final Report for Period 1 April 1979–13 June 1980

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Conversion factors for U.S. customary  
to metric (SI) units of measurement.

To Convert From	To	Multiply By
pounds	grams	453.6
feet	millimeters	30.48
feet	meters	.3048

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## NOMENCLATURES

		<u>Units</u>
$\rho_d$	Dust Density	$\text{gm}/\text{M}^3$
$\sigma_{\max}$	Maximum Dust Particle Diameter	mm
$h$	Altitude	km, kft
$\sigma/\sigma_{\max}$	Normalized Particle Diameter	
$\rho_{\text{ice}}$	Ice Density	$\text{gm}/\text{M}^3$
$\sigma$	Equivalent Ice Sphere Diameter	mm
$\alpha$	Angle of Attack	deg
$V$	Velocity (Missile)	cm/sec
$t$	Time	seconds
$R, \text{Rad}$	Nose Radius	inches
$C_N$	Erosion Parameter	joules/gm
$\sigma_i$	Impact Incidence Angle	deg
$\Delta S$	Surface Recession	$10^{-3}$ inches
$C_O$	Drag Coefficient	
$M_a$	Mach Number	
$N_c$	Number of Particles	
$C_C$	Cross-section for Backscatter	
$\beta_a$	Clean-Air Backscatter Coefficient	
$P_p$	Received Power (Backscattering from Particles)	
$P_a$	Receiver Power (Backscattering in Clean Air)	
$m$	Mass Removed per Unit Area	$\text{gm}/\text{cm}^2$
$\rho$	Eroded Material Density	$\text{gm}/\text{cm}^3$
$C_N$	Erosion Parameter	joule/gm
$\lambda$	Flight Path Length through Eroding Particles	cm

## SECTION 1

### SUMMARY

A system analysis feasibility investigation was undertaken to evaluate the potential of an in-situ, real-time measurement system of the dust/pebble environment in the vicinity of an advanced missile field when under attack. These sensor(s) are to provide two discrete information bits: a time integrated value for dust density and a time variable maximum particle size with altitude. These data are to be used to determine if the dust/pebble environment has become tenuous enough for missile flyout. A matrix of similar sensor type/sensor location combinations were investigated resulting in three combinations being recommended for further consideration.

## SECTION 2

### INTRODUCTION

Current specifications for the development of an advanced land based ICBM specify a series of erosive environments in which the missile must survive during launch operations. While a reasonable expectation exists that design hardening of the missile will be accomplished to meet these requirements, the specifications as given, are not time or space variant, thus do not provide guidance regarding launch window timing.<sup>1</sup> This required launch information is available currently by predictive techniques, such as hydrocode or analytical models which show potentially unacceptably large uncertainties in initial launch time sure-safe conditions. Moreover, our attempts to validate predictive models are hampered by a seeming myriad of variables such as, the extrapolation of uncertainties of H.E. test results to nuclear conditions, effects of soil types, initial conditions of the calculations and natural effects such as winds.

These uncertainties are so critical to the sure-safe operation of the missile during its launch phase that they cannot be tolerated. An alternative approach investigated here is the feasibility of an in-situ sensor system (designated FREE - Field Remote Environment Evaluation) located in the missile launch field to provide real-time interrogation of the erosive environment during attack or post-attack conditions. The immediate improvement over the current approach is apparent; i.e., the effects of soil type, initial conditions, winds, natural water and ice clouds and extrapolation of H.E. data to nuclear conditions no longer perturb launch window determination in an unknown manner. The major open issue is the

development of the concept, utilizing the appropriate sensor(s) to provide sufficient specification go/no-go information. This data is total integrated mass and maximum particle size data in a time-space reference. The key elements of this concept are the determination of the appropriate sensor(s), their numbers and cost, C<sup>3</sup> requirements and advantage/disadvantage comparisons with current predictive approaches.

## SECTION 3

### BACKGROUND

The FREE sensor concept is intended to provide an erosion/penetration environment in-situ interrogation system which provides real-time measurements of mass and particle size parameters so as to preclude the necessity of relying on predictive methods for launch window determinations. Typical specifications require delayed launch based upon prediction of decay in the erosion/penetration environment to an acceptable level (Figure 3-1). The environment is not sampled and the timing of the predicted launch window is possibly uncertain to within 5 to 10 minutes. Moreover, it can be expected that in a real attack, multiple burst cloud interaction will be present. While some visibility into this effect is obtainable (and being pursued) with H.E. experiments, extrapolation to the nuclear case is questionable due to the gross scaling of parameters; thus, in lieu of a real time measurement, confident predictions for launch are questionable.

In addition to the former points for a FREE sensor, the concept is viable regardless of the basing mode chosen for the advanced missile since the sensor units could be located in a grid form to provide a space-time picture of the post-burst environment for comparison with flyout threshold specifications. If desired, these data could be used to extrapolate to later times for pre-launch countdown initiation. In general, the need for a real time measurement can be summarized as shown in Figure 3-2. Basically, employment of this system would minimize the unknowns found in the predictive method.

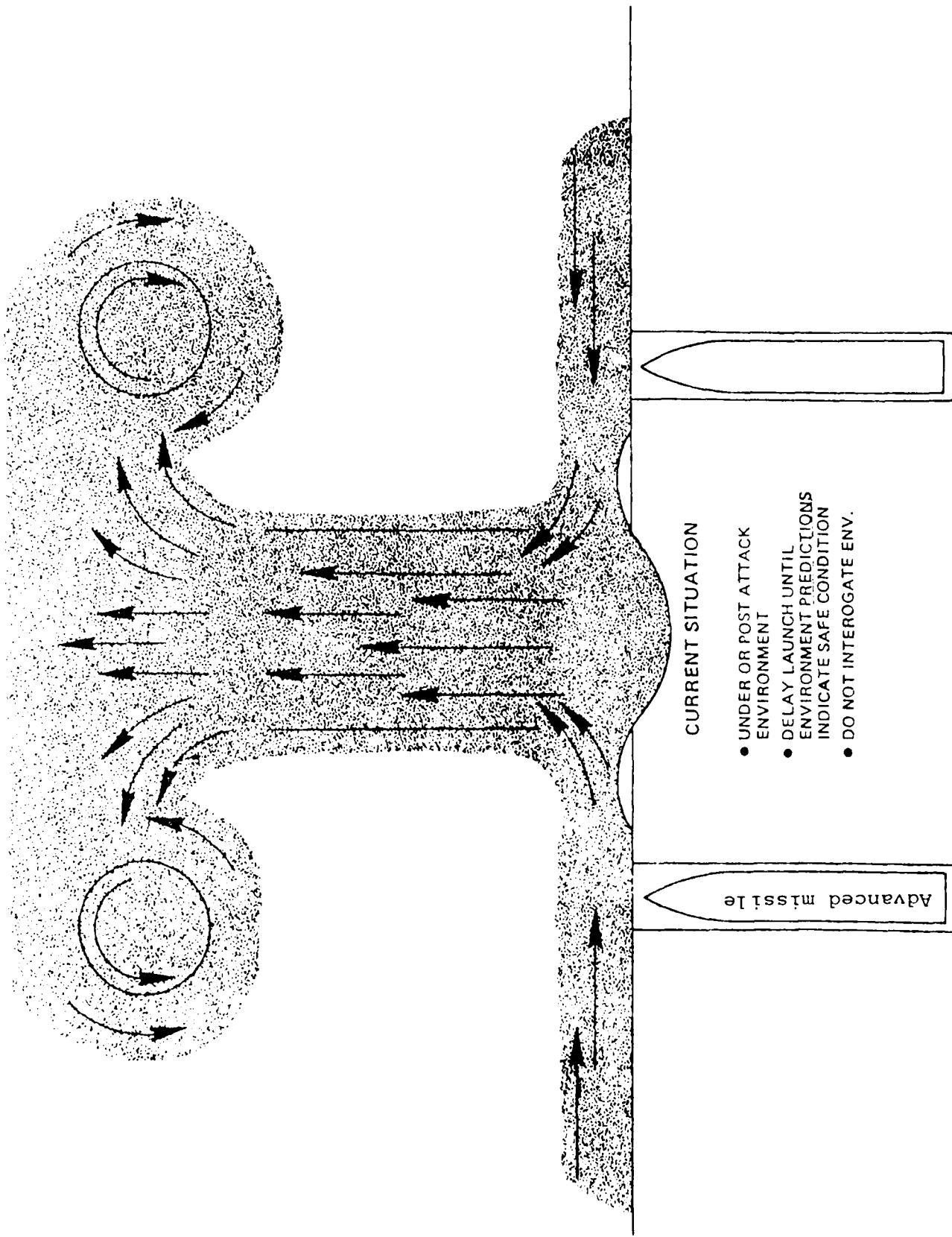


Figure 3-1. Dust environment schematic.

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#### LAUNCH SPECIFICATIONS

- requires survivability in flyout through erosive environment
- depends upon environment predictions to initiate launch
  - erosive
  - pebble

#### NUCLEAR EROSION/PEBBLE ENVIRONMENTS UNCERTAIN

- modeling of space-time history is not satisfactory for sure-safe launch window determination due to
  - attack scenarios
  - uncertainty in models
- modeling will not include effect of ambient conditions
- modeling check-out via H.E. testing is not likely to satisfy questions of scaling to large nuclear events either for:
  - single-burst
  - multi-burst

FREE SENSOR PROGRAM WOULD MINIMIZE ALL OF THESE UNKNOWNNS

---

Figure 3-2. Why develop the FREE concept

Several sensor types can be viewed as candidates to interrogate the post-attack environment (i.e., rocket, mortar, laser, etc.), however, the key points to address are:

- 1) Technical Feasibility
- 2) Survivability
- 3) Operational Concept
- 4) Cost
- 5) Maintainability

Without regard to sensor types (i.e., radar or rocket), points (1) and (2) are addressed in terms of the capability of the FREE units. It only requires that each element of a sensor grid measure and provide to launch control the total integrated mass and maximum particle size to be intercepted by the missile during the boost phase (Figure 3-3). If these parameters exceed the threshold design sure-safe level, additional interrogation would be made in a time sequence until a partial or full launch field window was present or available from extrapolation of apparent environmental decay measurements. The numerics of the deployment (number of units) and the geometry desired of the "grid" system may be peculiar to the missile-basing concept, thus are part of the suggested concept development program. A pictorial of the sensor layout is shown in Figure 3-4 for the multiple aimpoint (MAP) concept, while Figure 3-5 indicates key parameters for determining how many units will be needed.

---

- MEASURE AND REPORT

- total integrated mass  
(or a threshold ratio)
- maximum particle size  
(or a threshold ratio)

} to ensure safe flyout

- SENSOR UNITS IN LAUNCH FIELD TO:

- provide multiple point measurements
- map launch area
- provide data for space/time extrapolation
- give a final pre-launch sampling

---

Figure 3-3. Develop a field of in-situ erosion/  
pebble environment sensors

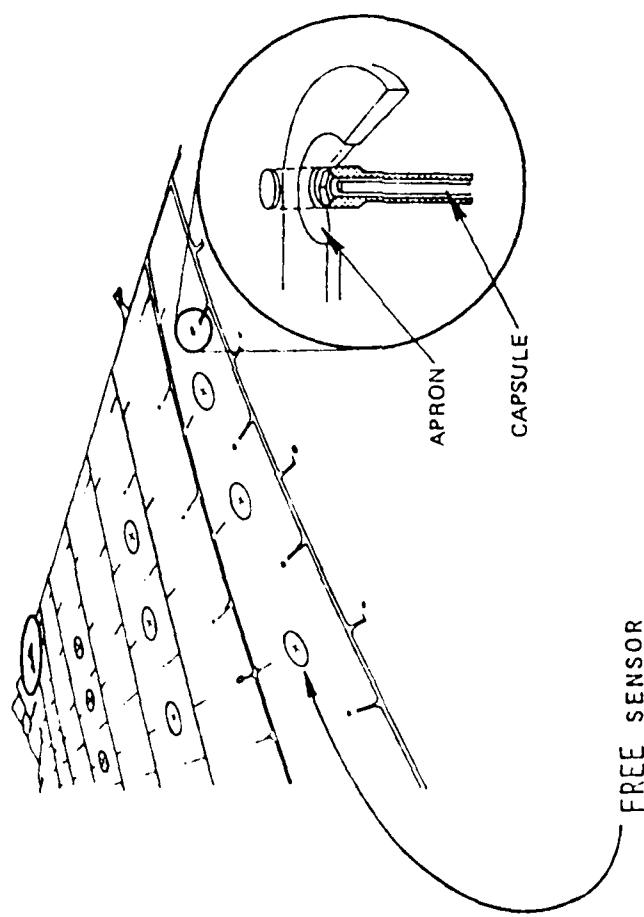


Figure 3-4. Field layout example (silo concept).

---

- DETERMINE BY GRANULARITY OF GRID DESIRED  
(upper limit - one per launcher)
- DETERMINE BY SAMPLE VOLUME AND SURVIVABILITY REQUIREMENTS
- DETERMINE BY PROGRAM COST LIMITATIONS
- DETERMINE BY ADDITIONAL C<sup>3</sup> COMPLEXITY

---

(U) Figure 3-5. Sensor locations.

## SECTION 4

### CONCEPTS AND ANALYSES

The FREE feasibility investigation program consists of eight tasks as defined in the Statement of Work. These tasks (identified below) and the analysis associated with each element are discussed in this section. Tasks 1, 6, 7 and 8 are considered in the greatest detail (Task 8 comprises the basic summation and is the basis for Section 5 - Results). Tasks 2-5 are more conceptual in nature at this time in the advanced missile development, thus are treated in less detail.

#### Tasks:

- 1) Define Advantage to Missile Survivability
- 2) Operations
- 3) Cost
- 4) C<sup>3</sup> Requirements
- 5) System Layout Scenario
- 6) Nominal Radar Requirement
- 7) Evaluate Alternate Sensors
- 8) Compare Detector (Sensor) Options

Details of each task follows.

#### Task 1 - Define Advantages to Missile Survivability

Current advanced missile specification for launch under attack mode include dust and ice nuclear-induced environments. These environments, taken from an advanced missile specification document<sup>1</sup>, are neither time nor space variant thus no understanding

of the expected launch window condition is available. The specification data show the variation with altitude of dust density in grams/cm<sup>3</sup> and maximum dust particle diameter in centimeters. Upper limits are nominally a few gm/cm<sup>3</sup> and several cm diameter. Dust particle size distribution function adapted for the specification is also specified. Similarly, the nuclear-induced ice environment altitude-density profile and the ice particle distribution function is prescribed.

The key issue, however, is the hold time required for an advanced missile before launch survivability can be guaranteed. Currently, given that it is designed to meet the specification, the launch window is based upon a prediction of expected environmental decay unsubstantiated by any nuclear test data. The environment is not sampled and the timing of the predicted launch window is possibly uncertain to within 5 to 10 minutes. Moreover, it can be expected that in a real attack multiple burst cloud interaction will be present. While some visibility into this effect is obtainable (and being pursued) with H.E. experiments, extrapolation to the nuclear case is questionable due to the gross scaling of parameters; thus, in lieu of a real time measurement, confident predictions for launch times are questionable.

The FREE concept is viable regardless of the basing mode chosen for the advanced missile since the sensor units could be located in a grid form to provide a space-time map of the post-burst environment for comparison with flyout threshold specifications. If desired, these data could be used to extrapolate to later times for pre-launch countdown initiation. In general, the requirements for a real time measurement can be summarized as shown previously in Figure 3-2. Basically,

3

employment of this system would minimize the unknowns found in the predictive method. This would be accomplished by providing a field of in-situ sensors to monitor the airborne particulate environment. The data requirements would be:

- o Measure and Report to the Launch Control Center (LCC)
  - total integrated dust mass  
(or a threshold ratio)
  - maximum pebble particle size  
(or a threshold ratio)
- o Sensor Units in the Launch Field to:
  - provide multiple point measurements
  - map launch area
  - provide data for space/time extrapolation
  - give a final pre-launch sampling

#### Task 2 - Operations

This task has been combined with Task 4 due to several common elements.

#### Task 3 - Cost

Subsequent to the establishment of technical feasibility, a detailed study of candidate sensor system costs must be undertaken. At this stage of investigation, only a first-order estimate of cost is made. It is based upon a ground based radar which is one of the viable candidate sensors selected from the study.

A key element in establishment of the FREE sensor as a viable concept is its cost relative to missile total deployment dollars. Clearly some threshold value, perhaps a fraction of a percent of total cost, could be established which dictates continuation or abandonment of this concept. The cost will be viewed in terms of how important it is to gain a few minutes in launch window as well as the confidence of sure-safe launch conditions.

If, for example, a ground rule of 0.5-1% of total system development and deployment cost is acceptable, the scaled costs per launcher (or per sensor) would be 0.5-1 million dollars\*.

With this level of possible funding\*\*, identification of elements of sensor costs are required. These elements are:

- 1) Sensor Unit Costs
- 2) Site Installation

A cursory investigation indicates that sensor unit cost may approach \$0.25-0.5 million each, depending on radar type. For specific radar configuration, details of the cost have to be determined.

Site requirements and installation costs have been considered briefly and are given here.

---

\* Based on 20 billion for the system.

\*\* Note again that this is one sensor per launcher. Actual number could be many less than this (perhaps as low as 20).

Goals of the program would include that the site be:

- 1) a simple structure
- 2) be blast hardened, at least at the level of missile ground basing facilities
- 3) be self contained.

The installation is envisioned as an underground concrete structure. Radar access to the outside environment would utilize a dielectric window, possibly in conjunction with a blast door. Seismic detection could be used to activate opening of such a blast door. The unit would be self contained having its own necessary power, heating, ventilation, and plumbing system. If no blast door is used, the dielectric window must act in that capacity.

An underground room of an approximate 10x10x10-foot size would house the FREE sensor system. Since the system could be installed at the same time as the missile silo system, the added expense of remote area construction should be avoidable as the missile site construction capability would be utilized.

The concrete structure would be built to U.S. Army Corps of Engineers' standards for blast hardening (probably requiring walls with double curtain reinforcement steel). The radar window could be a conically shaped dielectric material such as a high strength fiberglass. A conical shape would provide strength and would also be self cleaning to falling or flying debris.

The system would ordinarily be powered by the main missile complex power system. The FREE sensor would, however, have its

own diesel-powered generator which would operate in the event the main power system should fail. The consideration of an optional solar powered backup system could also be made to provide stored power reserve.

A "rough-order-of-magnitude" (ROM) cost for the installation of a prototype system might be as follows (includes burdens):

<u>Manpower</u>		(\$47,000)
Engineering	3 man-months	21,000
Tech "A"	6 man-months	26,000
<u>Construction Subcontracts</u>		(\$48,000)
Excavation & Backfill		2,500
Concrete Construction		21,000
Electrical/Mechanical Systems		2,500
Power Generation		14,500
Water System		9,500
<u>Blast Door - Option 1</u>		(\$25,000)
Construction Costs		25,000
<u>Solar Powered Backup System - Option 2</u>		(\$24,000)
Construction Costs		24,000
<u>Total System Installation Costs</u>		(\$95,000)
With Option 1		\$120,000
With Option 2		\$119,000

#### Task 4 - C<sup>3</sup> Requirements (also Task 2 - Operations)

A quick look at C<sup>3</sup> suggests that the information to be provided by FREE should cause minimal perturbation on the total

information system requirement. Figure 4-1 shows a pictorial of the information path required. The goal will be to provide the environment information in as timely and simple a manner as possible for rapid decision making. It is visualized currently that the needed data can be supplied in pictorial grid of sensor points within the missile field in which a color coded readout is provided as a go/no-go indicator. Further investigation is needed, however, based upon number of sensors, airborne or ground located launch control position and whether backup data readout is required at each launch point for autonomy.

#### Task 5 - System Layout Scenario

The physical layout of the system chosen is dependent upon specific basing options, unit costs, number of units and the granularity of the spatial data required. A simple schematic is shown for a silo concept in Figure 4-2. At the outset of this investigation, this task was included as a quick-look effort; however, the status of basing concepts has been so fluid as to preclude even a meaningful quick look comparison effort. Furthermore, details of the layout are partially driven by expected threat RV laydown patterns which will be defined when basing concepts are finalized. Since these key elements are still uncertain, the task remains incomplete.

#### Task 6 - Nominal Radar Requirement

The primary sensor candidate which offers the greatest promise is some form of radar interrogation system. The attractiveness of these systems are their fixed position as opposed to "active" (i.e., rocket) systems and the state-of-the-art in

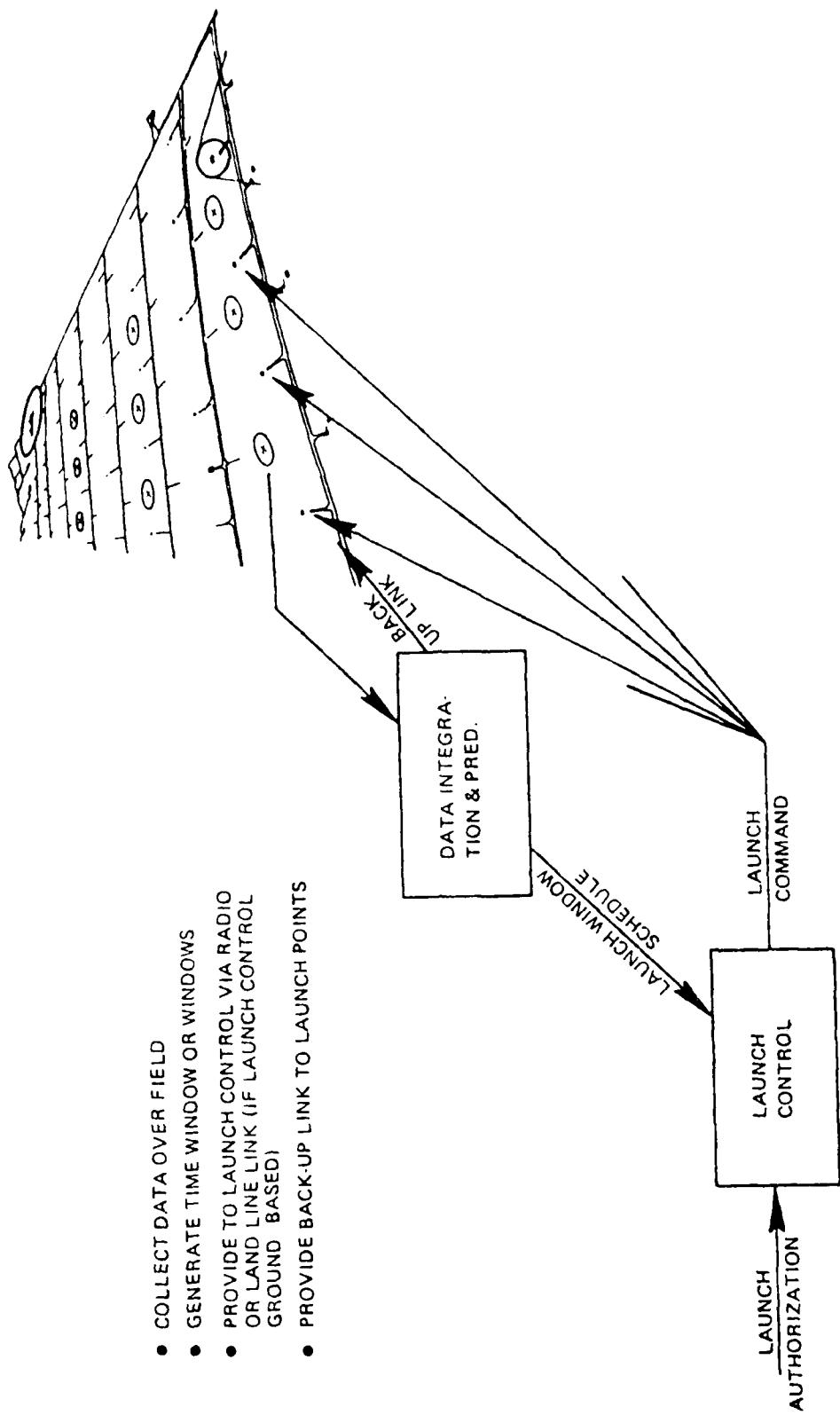


Figure 4-1. Command and control requirement.

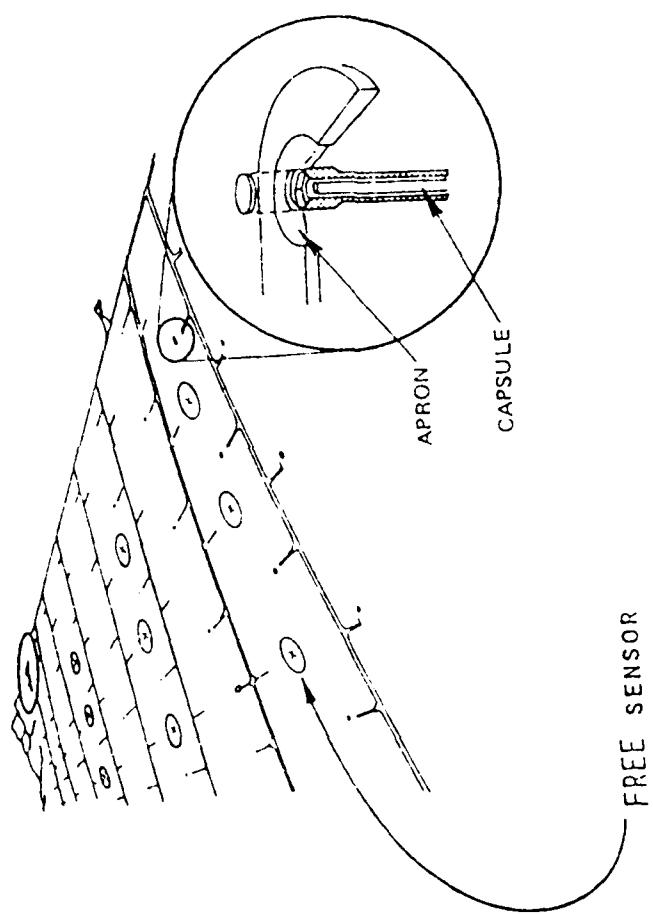


Figure 4-2. Field layout example (silo concept).

calibration understanding provided by their use in weather measurements and H.E. dust tests. In addition, further simplicity is envisioned here since fixed, non-tracking radars could be employed to simplify the hardening problems.

Calculations have been made to investigate which radar types are reasonable candidates; namely, doppler, bi-static and pulse-doppler. All systems appear to offer some desirable characteristics peculiar to their design, however, pulse-doppler may be the most desirable candidate from a viewpoint of simplicity, vulnerability and cost consideration. A series of figures is included showing the range of characteristics that may be needed. In Figures 4-3 and 4-4, pulse radar characteristics are shown which could supply the information desired.\* Trade-offs for antenna size and peak power are shown in Figure 4-5. Figure 4-6 shows a pictorial of how the unit might be setup in a subsurface field location.

A bi-static radar with a synchronous satellite as receiver is shown in Figures 4-7 and 4-8. Calculations indicate that antenna size and beamwidth present engineering problems much greater than the pulsed radar concept.

Basic doppler radar characteristics which bear on the dust measurement issue are given in Figure 4-9. The advantage over pulsed radar lies in the particle velocity measurement ability and lower peak to average power ratios needed. However, multiple range interval resolution is needed. In addition, test data on

---

\* Based on missile dust specification (Reference 1)

- S-C BAND RADAR
- FIXED VERTICAL LOOKING ANTENNA
- HARDENED (BURIED)
- OUTPUT
- RATIO OF RETURN SIGNAL/LAUNCH THRESHOLD LEVEL
- DISPLAY RATIO AS A "MAP" OVER ENTIRE FIELD

Figure 4-3. Pulse radar.

- FREQUENCY - 3 GHZ (S-BAND)
- POWER
  - AV - 3.7 KW
  - PK - 100 KW
- PULSE REP. FREQ. - 5500 Hz
- PULSE WIDTH -  $6.7 \mu\text{s}$
- ANTENNA
  - SIZE - 10' X 10'
  - BEAM WIDTH -  $2.2^\circ$  X  $2.2^\circ$
  - TYPE - PLANAR ARRAY
- TRADE-OFFS
  - ANTENNA SIZE-VS-TRANSMITTER POWER
  - SIGNAL ATTENUATION AT LOW ALTITUDES-VS-SIGNAL RETURN  
AT HIGH ALT. (FUNCTION OF FREQUENCY)

Figure 4-4. Example pulse radar characteristics.

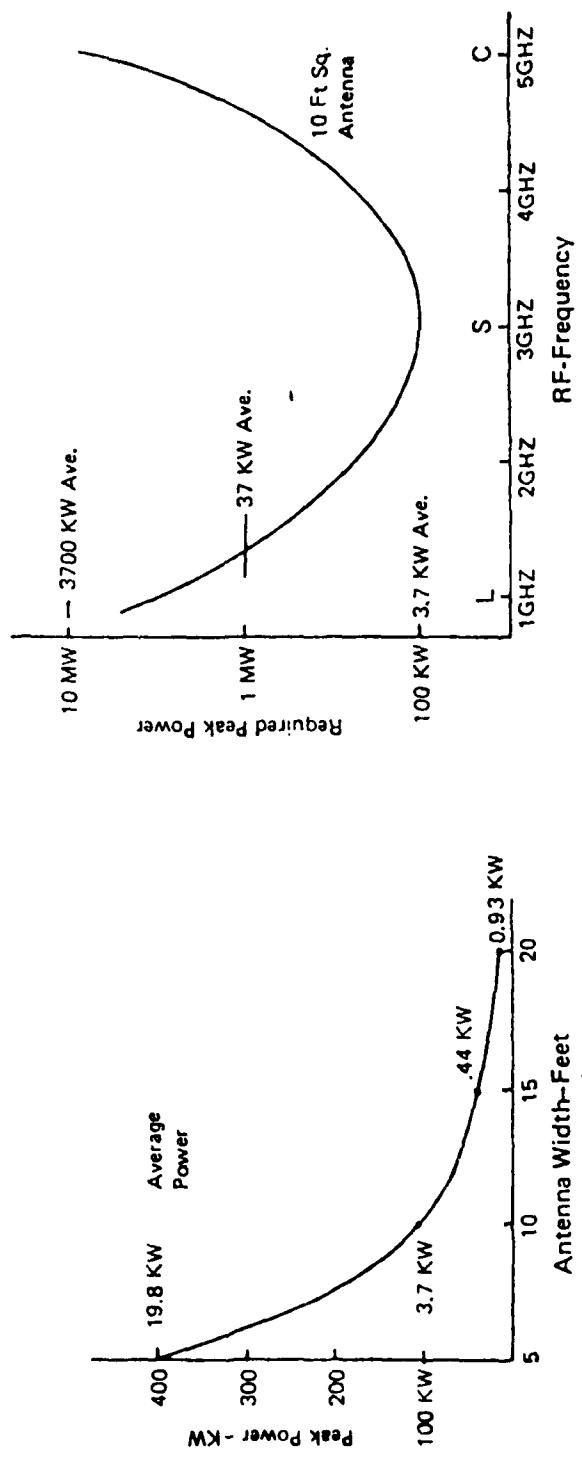


Figure 4-5. Dust sensor pulse radar tradeoffs.

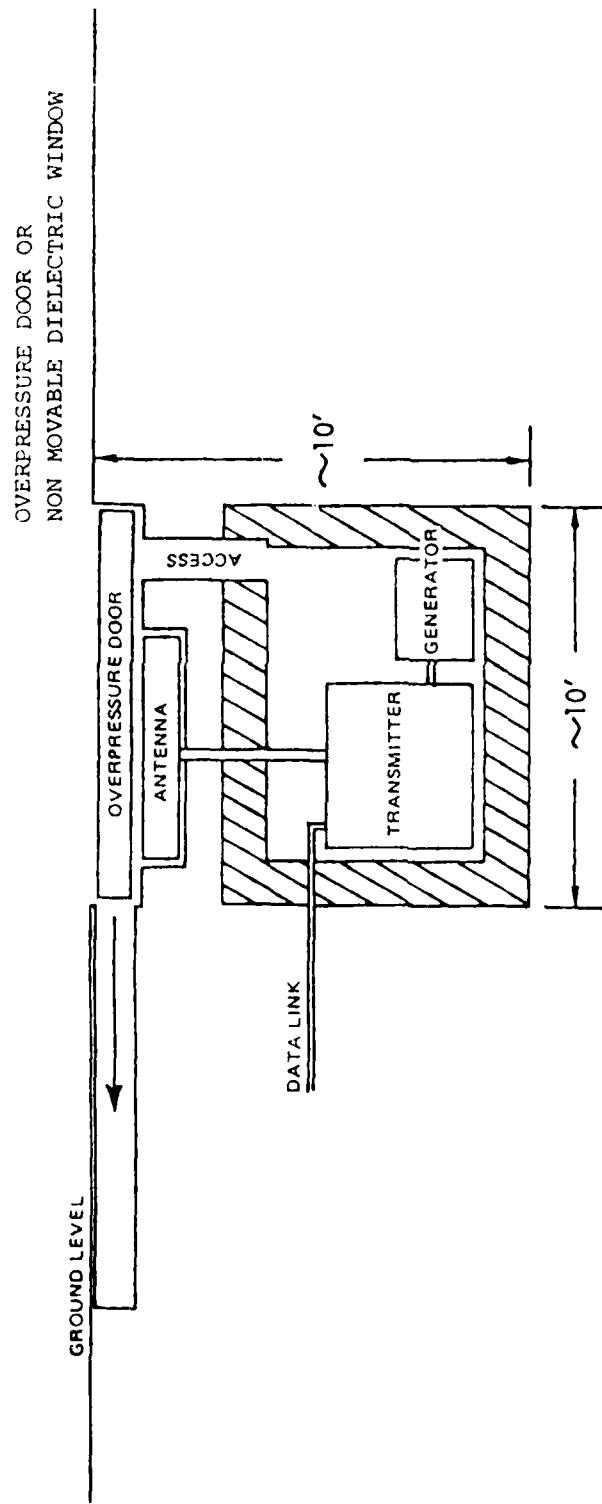


Figure 4-6. FREE radar unit pictorial.

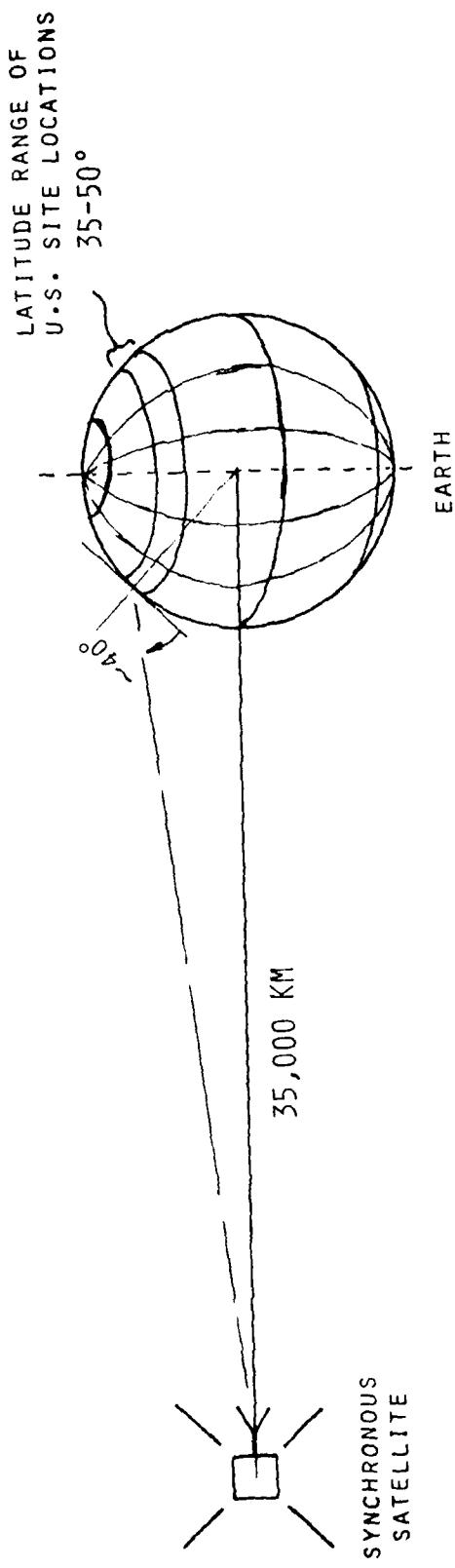


Figure 4-7. Satellite based receiver, land based transmitter.

- ATTENUATION MEASUREMENTS LIMITED TO  $\sim 40^\circ$  LOOK ANGLE WITH RESPECT TO HORIZON. (SYNCHRONOUS SATELLITE LIMITED TO EQUATORIAL ORBITS).
- TO MEASURE REFLECTED SIGNALS FROM THE DUST CLOUD WITH A SENSITIVITY COMPARABLE TO A 100 FT<sup>2</sup> SURFACE ANTENNA REQUIRES AN ENORMOUS ANTENNA ON THE SATELLITE.

$$\text{AREA} \geq 100 \text{ FT}^2 \left( \frac{35,000}{27 \text{ KM}} \right)^2 = 1.7 \times 10^8 \text{ FT}^2$$

- IF WE ASSUME A 10 TO 1 INCREASE IN POWER (TO 40 KW) AND A 10<sup>-1</sup> REDUCTION IN SPACE LOSSES, THIS STILL PUTS THE REQUIRED ANTENNA AREA AT :

$$2.7 \times 10^6 \text{ FT}^2$$

OR DIAMETER  $\sim 15,000$  FT

- THE BEAMWIDTH WOULD THEN BE  $\sim 0.02$  MILLIRADIANS OR  $\sim 0.013$  DEGREES.
  - EVEN IF SUCH AN ANTENNA COULD BE BUILT IT WOULD PRESENT EXTREMELY DIFFICULT POINTING AND STABILIZATION PROBLEMS.

Figure 4-8. Satellite based receiver, land based transmitter.

- DOPPLER RADARS ARE USEFUL FOR A NUMBER OF APPLICATIONS BECAUSE:
  - THEY ARE COMPUTABLE WITH LOW COST SOLID STATE DEVICES SINCE THEY REQUIRE LOW PEAK TO AVERAGE POWER RATIOS.
  - SIGNAL PROCESSING CAN BE VERY SIMPLE IF ONLY A FEW RANGE GATES ARE REQUIRED.
- A PURE DOPPLER RADAR MAY NOT BE USEFUL IN THIS APPLICATION, HOWEVER, BECAUSE:
  - SINCE THE TARGETS WE ARE LOOKING FOR ARE CLUTTERLIKE IN THAT THEY HAVE DISTRIBUTED RANGES AND VELOCITIES THE DOPPLER RADAR WILL NOT IMPROVE SIGNAL DETECTION CAPABILITY.
  - MULTIPLE RANGE INTERVAL RESOLUTION IS REQUIRED SINCE THE EXPECTED SIGNAL LEVELS WILL DECREASE DRastically WITH ALTITUDE. A RADAR THAT AVERAGES ALL RANGE INTERVALS UP TO 27 KM WOULD IN EFFECT SENSE ONLY THE LOWER ALTITUDES.

Figure 4-9. Doppler radar.

shroud erosion and pebble penetration shows a preponderance of penetration-related effects indicating that the doppler measurement element is a high priority.<sup>2</sup>

The combined pulse-doppler radar characteristics are given in Figure 4-10. Based upon the first-order analysis comparison, this appears to be the best overall radar system to consider.

#### Task 7 - Evaluate Alternate Sensors

The potential sensor systems identified as possible alternatives to the radar were:

- o OPTICAL (i.e., LIDAR)
- o DIRECT EROSION MEASUREMENT (Rocket Probe)
- o DIRECT CLOUD MICROPHYSICS MEASUREMENT
- o FALLOUT
- o ADVANCED BOOSTER

All of these systems in some manner can be judged capable of providing the needed data. However, key elements that must be present for any concept are:

- 1) Timeliness - If the sensor cannot produce the needed information in a real-time frame and thus reduce the launch hold period compared to analytical prediction , it fails to meet the system needs.
- 2) Missile Launcher Survivability - If the sensor concept in anyway reduces the number of operationally survivable advanced missiles, it is unacceptable.

- A PULSE DOPPLER RADAR CAN PROVIDE BOTH RANGE AND VELOCITY (DOPPLER) INFORMATION
- VELOCITY DATA MAY PROVIDE ADDITIONAL INSIGHTS INTO PARTICLE SIZE DISTRIBUTION TO BACK UP AMPLITUDE MEASUREMENTS
- RANGE RESOLUTION MAKES IT POSSIBLE TO COMPENSATE FOR THE CHANGE IN SIGNAL RETURN WITH ALTITUDE DUE TO
  - BEAM SPREADING WITH RANGE
  - PARTICLE SIZE DECREASE WITH ALTITUDE
  - ATTENUATION AT THE LOWER ALTITUDES
- A PULSE DOPPLER RADAR REQUIRES A STABLE FREQUENCY REFERENCE AND A MORE SOPHISTICATED SIGNAL PROCESSING SYSTEM BUT THIS WILL PROBABLY NOT REPRESENT A LARGE PERCENTAGE OF THE TOTAL COST WHICH WILL BE DRIVEN PRIMARILY BY THE HIGH POWER ELEMENTS AND THE HARDENED ANTENNA SYSTEM

Figure 4-10. Pulse - Doppler radar.

With these two requirements in mind, the acceptability of alternate sensors is discussed.

- o Optical

The use of optical systems such as light detection and ranging (LIDAR) and infrared techniques were investigated briefly to judge their utility to providing the data required for the FREE system.

Some success<sup>3,4</sup> has been achieved on past programs with these systems to provide the total number of particles in an effective scattering volume based upon the general relationship:

$$(\sum_c N_c C_c)_{\text{eff}} = \frac{P_p}{P_a} \beta_a$$

where  $N_c$  = number of particles

$C_c$  = cross-section for backscatter

$\beta_a$  = clean-air backscatter coefficient

$P_p$  = received power (backscattering from particles)

$P_a$  = received power (backscattering in clean air)

This relationship is generally viewed as a summation of individual "LIDAR" products  $(\sum_c N_c C_c)_{\text{eff}}$  for discrete particle size ranges such that

$$(\sum_c N_c C_c)_{\text{eff}} = N_{c_1} C_{c_1} + N_{c_2} C_{c_2} + \dots$$

Results from various experiments and test programs have shown that at the wavelengths used in the optical range (i.e., 1 -20  $\mu\text{m}$ ) that an adjunct system is highly desirable to provide discrete values for the  $C_{c_i}$  factors. The implication is that using an overall

effective  $C_{C_i}$  over the entire distribution is undesirable for accuracy. Furthermore for very dense clouds, which are typical of early time dust volumes, extinction of the optical beam is probable for times longer than acceptable for launch window predictions. Finally, explicit maximum particle size determination, the key parameter, is not provided by this technique, thus utilized independently the system cannot provide timely data.

- o Direct Erosion Measurement (Rocket Probe)

This concept appears to provide a system potentially competitive to the radar system in providing useful go/no-go data for launch window determinations. In principle the rocket can provide:

- total integrated mass through a vertical sample volume or over a designated flight path
- maximum particle sizes within the flyout corridor

The data are obtained as represented by a simple  $C_N$  model\*

$$m = \frac{\rho}{2C_N} v^2 \lambda$$

where  $m$  = mass removed per unit area,  $\text{gm/cm}^2$   
 $\rho$  = eroded material density,  $\text{gm/cm}^3$   
 $C_N$  = erosion parameter,  $\text{joule/gm}$   
 $v$  = impact velocity,  $\text{cm/sec}$   
 $\lambda$  = flight path length through eroding particles,  $\text{cm}$

\*Practically a multiparameter model would be needed for more accurate representation; however, the data readout to the LCC would still be a go/no-go color code.

This measurement is one step removed from the specified environment but probably correlatable with acceptable accuracy. The concept is relatively cheap as well as potentially invulnerable to nuclear effects. Rocket probes could be designed to simulate actual advanced missile erosion and penetration thresholds; however, information retrieval would need to be demonstrated.

- o Direct Cloud Microphysics Measurement (i.e., Knollenberg Probes)

In general these systems are too slow. In addition, they would require many units that are expensive and vulnerable to loss as in the case of remotely piloted vehicle (RPV) flythrough. Considerable development would be required to eliminate these debits. They could, however, provide detailed environmental data.

- o Fallout (Collection)

This concept is clearly the cheapest and simplest, but suffers dramatically from never being in the flyout altitude corridor. Moreover, utilization is much too slow.

- o Advanced Missile

The use of an advanced missile as its own sensor violates requirement 2 -- depletion of advanced missile launchers. The implied expense is also very high if viewed in terms of relative costs.

## SECTION 5

### RESULTS

Based on the analysis in Section 4, the results of this investigation seem most properly viewed as a matrix of sensors, locations and system development factors considered in the study (Task 8). Several arrays were considered resulting in two which show succinctly those sensor applications amenable to the FREE concept, namely:

- 1) Sensor vs. Location
- 2) Sensor vs. Figure of Merit

The relative figure of merit ratings were arbitrarily picked as excellent, good, fair and poor. The definition of the ranking factors, although arbitrary, were rigorously adhered to in final ranking. These definitions are given here.

- 1) Excellent - The system must be able to produce the desired information without question, with little development, complexity, risk or excessive cost.
- 2) Good - The system is somewhat less developed, more complex or risky and/or more expensive than one rated excellent.
- 3) Fair - Potential for providing the desired measurement exists, however, is generally more complex or slower than the excellent/good combinations.

- 4) Poor - Serious question exists for this system to provide timely accurate data input.

In order for any system to attain one of these four merit ratings, a minimum of one of the matrix elements was required to possess at least that high a level of merit.

An example of the development of these matrices is shown for clarity of the final rating scheme. The six categories of sensors are shown in the left column of Figure 5-1 with five potential sensor locations described at the top from left to right. In this matrix the goal was to identify only those sensor/location combinations which were physically reasonable. For example, clearly a ground located radar (column 1 - row 1) is a reasonable combination whereas a direct erosion measurement by rocket from a satellite (column 4 - row 3) is unreasonable from rocket size requirements and complexity. When these considerations are given to all elements of the 6x5 matrix, only nineteen combinations remained. These nineteen, as identified by the "X's" were then investigated further regarding their applicability to the FREE concept.

Applying the previously discussed figure-of-merit relationships, the general matrix of Figure 5-1 was altered to include the relative ratings of the matrix elements. This is shown in Figure 5-2. The elements or sensor/location combinations indicated as good to excellent are FREE candidates. All other combinations, for one reason or another, rated fair to poor. The excellent to good candidates were:

	GROUND & AIRCRAFT LINK		SATELLITE & GROUND LINK	
	GROUND	AIRCRAFT	SATELLITE	SATELLITE
RADAR	X	X	X	X
LIDAR	X	X	X	X
EROSION MSMT (DIRECT) (ROCKET)	X	X	X	X
CLOUD MSMT (DIRECT)	X	X	X	X
FALLOUT MSMT	X		X	
ADV. MISSILE		X		

Figure 5-1. Environment detection options.

	GROUND	AIRCRAFT	GROUND & AIRCRAFT LINK	SATELLITE
	GROUND	AIRCRAFT	LINK	SATELLITE & GROUND LINK
RADAR	E	G	F	F
LIDAR	F	P	P	P
EROSION MSMT (DIRECT) (ROCKET)	G	F	P	
CLOUD MSMT (DIRECT)	P	F	F	
FALLOUT MSMT	P	P		
ADV. MISSILE		F		

E - Excellent  
G - Good  
F - Fair  
P - Poor

Figure 5-2. Environment detection options.

- 1) radar/ground based
- 2) radar/airborne
- 3) erosion measurement (rocket)/ground based

The next series of figures illustrate how the final figure-of-merit rankings were arrived at using the ranking factors of this investigation. (The radar/ground based is used as an example). In Figure 5-3, the ranking factors, common to all matrix elements, are shown. Based upon the results of the analysis section, each of the factors was evaluated. While no numerical rating was assigned to these factors, it was reasoned that technical feasibility was preeminent, therefore it is listed first. If a matrix candidate received a technical feasibility rating of less than "established", it was viewed as unworthy of a final excellent or good rating. Furthermore if a final rating less than good was assigned, the recommendation is that the sensor system be dropped from further consideration. For the radar/ground located system shown here (Figure 5-3), the technical feasibility has been established. Similarly the other ranking factors -- survivability, operational concept, risk and cost -- are shown.

From Figures 5-4 through 5-8, additional specific summations of the ranking factors are given based on the analysis of Section 4. These points, for each ranking factor, lead to the single judgment shown on Figure 5-3 and hence a general ranking as shown in Figure 5-2, the environment detection option matrix. In this case, the radar/ground based option was excellent -- the only option with that rating.

Finally, one additional option matrix layout is shown where the sensor is rated against the figure of merit (Figure 5-9).

---

TECHNIQUE/LOCATION

Radar (S-Band with Doppler) /  
Ground Collocated or Ground Remote

RANKING FACTORS

1. TECHNICAL FEASIBILITY

Established

2. SURVIVABILITY

As good as missile and/or LCC

3. OPERATIONAL CONCEPT

Simple

4. RISK

Low

5. COST

Low (<1.0% of total system cost for  
200 units)

---

Figure 5-3. EDO (Environment Detection Options).

---

CAN IT MEASURE THE PARAMETERS OF INTEREST?

Yes            1. Total integrated mass  
                  2. Maximum particle size

HOW ACCURATELY?

Factor of two (particle size)  
±100% (integrated density)

STATISTICAL REPRESENTIVITY OF SAMPLE VOLUME?

1) High - for beam widths on order of  $\leq 1^\circ$   
2) Reduced to low for large beam widths  $\gg 1^\circ$

---

Figure 5-4. Technical feasibility.

---

MUST THE SYSTEM BE HARDENED?

Yes

HOW HARD?

Level of missile shelter or LCC

COST TO HARDEN?

Low - if collocated

---

Figure 5-5. Survivability.

---

WHAT DOES IT LOOK LIKE?

Fixed Vertical Looking/No Tracking Required

OUTPUT?

1. Max. Particle Size with Altitude
2. Integrated Total Mass in Sample Volume

HOW TO COMMUNICATE?

Ground link to LCCs from remote locations  
(or from missile locations)  
or collocated with LCCs

COMPLEXITY?

Minimal - will provide

1. Go
2. No Go

Indicator to launch control center from  
each unit

---

Figure 5-6. Operational concept.

---

OVERALL RISK?

Low (SOA)

FALLBACK POSITION FOR LAUNCH CLEARANCE?

Current calculation

---

Figure 5-7. Risk.

---

HOW EXPENSIVE IS EQUIPMENT?

Low (<1.0% of total system cost for 200 units)

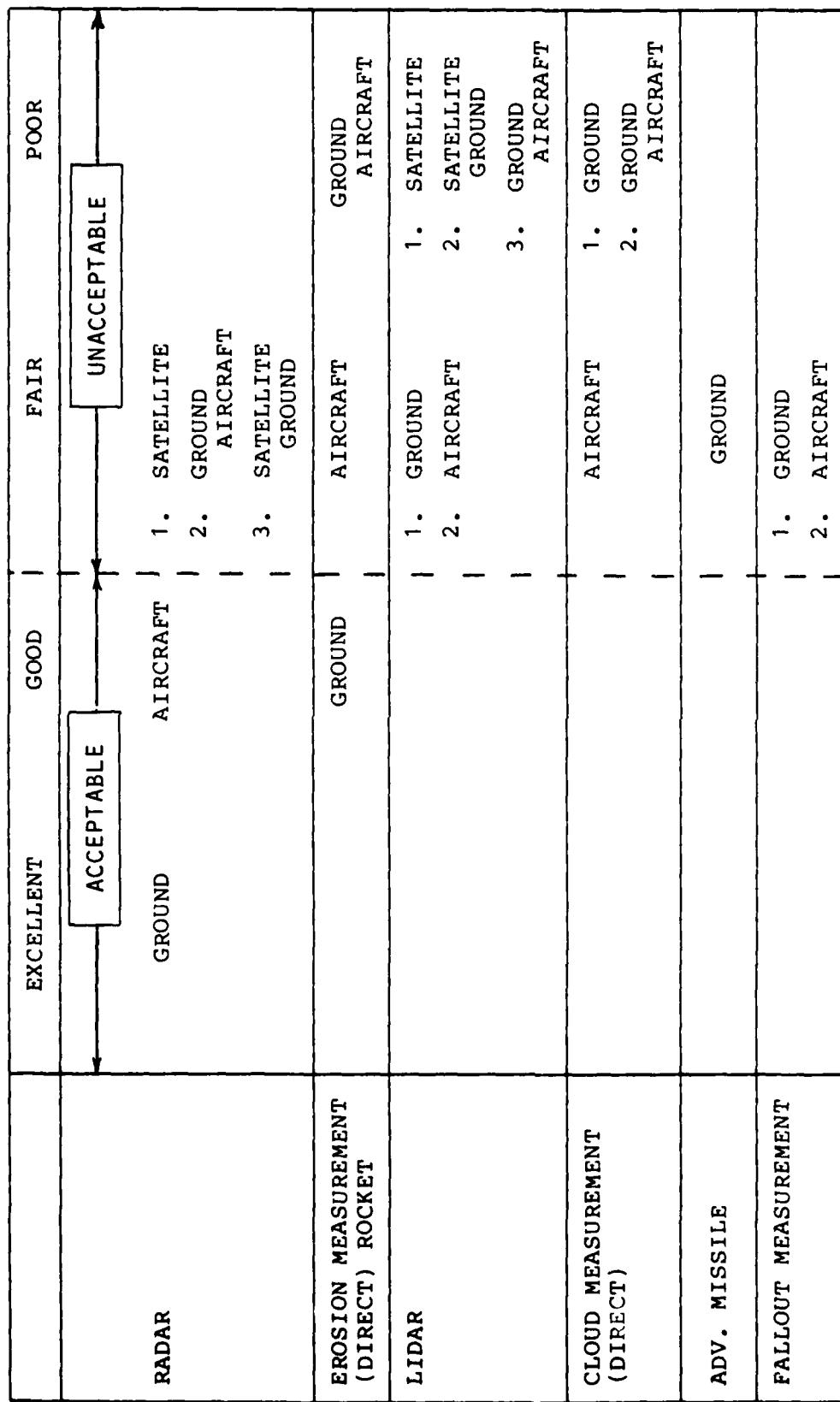
---

LIFE CYCLE COSTS?

To Be Determined (TBD)

---

Figure 5-8. Cost.



(U) Figure 5-9. FREE figure of merit.

Here the matrix elements contain the sensor locations. Also a visual measure of the acceptable-vs-unacceptable combination is readily clear although not detailed as to the reasoning for the choices which was previously discussed (and reiterated again in the Conclusion section).

## SECTION 6

### CONCLUSIONS

A first-order system analysis investigation of a real-time in-situ sensor for measuring integrated dust density and maximum particle size with altitude in an advanced missile field has been conducted. Nineteen combinations of sensor types/sensor locations were considered which resulted in three combinations being indicated for further analysis and experimentation. These candidates are:

- 1) Radar/ground based
- 2) Radar/airborne
- 3) Dust measurement (rocket)/ground based

Areas of investigation which were indicated for further analysis are the communication, command and control (C<sup>3</sup>) interaction and time line costing. These investigations should be undertaken within the context of various basing mode concepts. Furthermore, a more detailed sensitivity analysis should be pursued with regard to the accuracy of the radar and rocket measurements and the implication of those uncertainties on the missile flyout time window.

As a parallel effort, an experimental measurement program using large high explosive bursts (H.E.) should be pursued which demonstrates compliance with any missile dust specification questions; namely, surface erosion and large particle penetration of structural components. If fielding a reasonable missile specification level dust field is unattainable, a demonstration of the sensor measurement ability must be shown in conjunction with other redundant measuring systems.

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